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THE NATURAL RESISTANCE OF GHANAIAN WOODS TO 'COPTOTERMES FORMOS--ETC(U)

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The Natural Resistance of Ghanaian Woods to *Coptotermes formosanus* Shiraki in a Force-Feeding Situation.

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The natural resistance of 42 Ghanaian tropical woods to damage by *Coptotermes formosanus* Shiraki in a force-feeding situation was determined. All termites closeted with 26 woods died before the end of 8 weeks, and in some instances within 1 to 5 weeks. The latter insects probably were the victims of systemic poisons volatilizing from the wood in the test chambers, since early death precludes starvation. Most of the woods were lightly damaged, which suggests a repellent substance in the wood and death by starvation, but insects that died in as little as 2 weeks had fed heavily on some woods. There was an inverse relationship between wood density and the amount of wood damage. Supplementary data gathered by others is also given.

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CONTENTS

THE NATURAL RESISTANCE OF GHANAIAN WOODS TO *Coptotermes formosanus* SHIRAKI IN A FORCE-FEEDING SITUATION

INTRODUCTION

Termites are responsible for much of the degradation of wood and other cellulosics in the terrestrial environment. Because of the extensive damage caused by these insects to a variety of materials such as paper, fabrics, wooden structures, and even such noncellulosics as asphalt, abestos, bitumen, lead [1], and metal foils [2], a constant effort is directed toward their control.

Susceptible materials are protected by spraying, painting, dipping or impregnating them with a vehicle containing a chemical toxic or repellent to the termites or by treating the soil beneath and around structures to be protected. Unfortunately, an increasing number of these protectants is becoming unacceptable environmentally, and their use is being discontinued. One solution to this growing problem is to develop new antitermitics that are less offensive to the environment; another is to seek woods having natural resistance to termites. This latter course is becoming more attractive as governmental approval of new protectants becomes more difficult to obtain.

Because the U.S. Government is a large user of wood in the marine and terrestrial environments, it is vitally interested in protecting its investment by materially extending the service life of this wood. Consequently, the Navy and the Forest Service of the Department of Agriculture continually seek new protective measures which will reduce the cost of replacement or repair of biodamaged wood and still be environmentally acceptable. The Naval Research Laboratory and the Forest Service have been actively engaged in such research for may years, earlier from the standpoint of developing new antitermitic agents [3,4] and, more recently, in a search for naturally termite-resistant woods [5-8] and the identification of their antitermitic extractives. The work reported here is the result of cooperative research between the Naval Research Laboratory, the Southern Forest Experiment Station (USDA), and the Forest Products Research Institute [Kumasi, Ghana], on the laboratory evaluation of a number of African tropical woods for their natural termite resistance.

EXPERIMENTAL PROCEDURE

Termite workers beyond the third instar were taken from a colony of *Coptotermes formosanus* Shiraki collected from a bald cypress snag near Lake Charles, Louisiana. This voracious Asian species has become established recently around the two largest ports of the gulf coast [9], and its spreading range is cause for concern. It is an extremely destructive species and is infesting woods that are resistant to attack by native termites. This destructiveness makes *C. formosanus* a good species to use for these studies.

The experimental woods were supplied by the Forest Products Research Institute of Ghana; this organization also performed the wood identifications. The wood specimens were

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cut from the outer heartwood of the butt ends of mature trees and as near to the heartwood/sapwood interface as possible. When there was no visible distinction between the heartwood and sapwood the specimens were cut inward 10 cm from the debarked perimeter of the bole.

Circular plastic containers 5.0 cm in diameter and 3.5 cm in depth were packed with 50 g of sterile sand which was then moistened with 7 ml of distilled water to keep the relative humidity near saturation. One test block was placed on the surface of the sand in each container, and 50 termites were added. An assembled and charged test chamber is shown in Fig. 1. Southern pine sapwood was used as a very susceptible control wood against which performance of the other woods could be compared and also to observe the viability of the enclosed termites; starvation checks were made by adding termites to chambers containing only sand. The test chambers were maintained between 24° and 25°C for 8 weeks. Three replicates from the same tree were used for each wood evaluated.

A visual examination of each chamber was made weekly to determine the general health of the termites. If they appeared dead, that test was discontinued, and the survival time was recorded. At the termination of the exposure, the surviving termites in each chamber were counted. Wood damage was estimated by visual examinaton and was rated as follows: 0 — no detectable damage, 1 — light damage (etching), 2 — moderate damage, and 3 — heavy damage.

Fig. 1 — Typical test chamber containing wood specimen, sand, and termites

RESULTS AND DISCUSSION

The natural resistance of wood to termite attack may be ascribed to several causes. One of the physical factors is wood density, which influences the termite's ability to fragment the wood mechanically with its mandibles, and correlations between wood density and resistance to attack have been reported [10,11]. Protection against these insects is also provided by extractives within the wood tissues. These chemical constituents, generally not present in large quantity, make the wood distasteful, act as repellents, act as poisons toward the protozoan inhabitants of the termite gut, or act as systemic poisons toward the termites themselves. Each of these modes of action of wood extractives can often be associated with a specific termite response, e.g., an early death by the termites which precludes starvation and suggests the presence of a systemic poison in the wood. The results of this study on the natural termite resistance of these 42 tropical woods suggest that all the cited mechanisms may have been operating, singly or in consort. These results are presented in Table 1, which also includes the botanical name with author citation for each wood, its density, and a common name. An alphabetical cross-reference of common and botanical names is presented in the Appendix. By necessity only one or two of the many common names possessed by most of these woods are given, and the selected names are those in use in Ghana [12,13]. Various densities have been reported for many of these woods depending upon the method of determination; the density values reported here are for wood in an air-dry condition [13,14].

The observed wood-termite interactions fell into one of four groups: (1) no termite survival and no detectable wood damage, (2) no termite survival and wood damage, (3) termite survival and no detectable wood damage, and (4) termite survival and wood damage.

No Termite Survival - No Detectable Wood Damage (Group 1)

Coptotermes formosanus did not feed (no detectable wood damage) on 19 of the 42 woods evaluated and the termites were unable to survive for the full 8 weeks of exposure on 26 of these woods. Termites confined with *Mansonia altissima* and *Piptadeniastrum africanum* were all dead within 1 week, and those with *Albizia ferruginea, Manilkara multinervis, Morus mesozygia,* and *Erythrophleum ivorense* were all dead within 2, 3, 4, and 5 weeks, respectively. Since termites are able to survive on sand without food for up to 6 weeks [8], we suggest that some toxicant in the wood was affecting them. None of the termites survived the 8 weeks of exposure in the absence of wood.

No Termite Survival - Wood Damage (Group 2)

Coptotermes formosanus also did not survive the 8 weeks of exposure when confined to the test chambers with 14 others of the evaluated woods; however, in these cases the woods were damaged by the termites before they died. This damage varied considerably among these woods. Some of them apparently were distasteful to the termites since the insects left them alone after an exploratory nibbling lightly damaged the wood surface (rating — 1); other woods, however, were moderately (rating — 2) or heavily (rating — 3) damaged during the 8 weeks. For three of the moderately damaged woods, all the termites in the test chambers died. Termites confined with *Cleistopholis patens* were dead within 4 weeks; termites confined with *Parkia bicolor* and *Triplochiton scleroxylon* were all dead by the end of the exposure. Finally, *Lovoa trichilioides* was heavily damaged by *C. formosanus* during the 4 weeks members of this captive colony were able to survive.

Table 1 — Damage sustained by tropical African woods exposed to attack by captive colonies of *Coptotermes formosanus*. The rating scale is: 0 — no detectable wood damage, 1 — light wood damage, 2 — moderate wood damage, and 3 — heavy wood damage.

No.	Botanical Name	Common Name[a]	Density[b] Range (g/cm³)	Percent Termite Survival (Av)	Rating
1.	*Afzelia bella* Harms	Papao	0.65-0.72	9	0
2.	*Albizia ferruginea* (Guill. & Perr.) Benth.	Awiemfo-samina (Albizzia)	0.46-0.72	0 (2 wk)	0
3.	*Anogeissus leiocarpus* (DC) Guill. & Perr.	Kane	0.91-1.14	0	0
4.	*Antrocaryon micraster* A. Chev. & Guill.	Aprokuma	0.51-0.57	83	3
5.	*Canarium schweinfurthii* Engl.	Bediwonua	0.33-0.64	67	3
6.	*Cedrela mexicana* M. Roem. (Syn. *C. odorata* L.)	West Indian cedar	0.37-0.75	0	1
7.	*Celtis mildbraedii* Engl. (Syn. *C. soyauxii* Engl.)	Esa	0.58-0.80	14	2
8.	*Chlorophora excelsa* (Welw.) Benth. & Hook. f.	Odum (Iroko)	0.51-0.80	10	0
9.	*Chrysophyllum pruniforme* (Pierre) Engl.	Duatadwe	0.67	0	0
10.	*Cleistopholis patens* (Benth.) Engl. & Diels	Ngo Ne Nkyene, Otr	0.35-0.45 (4 wks)	0	2
11.	*Combretodendron macrocarpum* (P. Beauv.) Keay (Syn. *C. africanum* Welw. ex Benth.)	Essia	0.73-1.01	25	0
12.	*Coula edulis* Baill.	Bodwe	0.91-1.01	0	0
13.	*Daniellia ogea* (Harms) Rolfe ex Holland (Syn. *D. similis* (Craib))	Hyedua (Ogea)	0.41-0.57	74	3
14.	*Dialium aubrevillei* Pellegr.	Dua-bankye	—	52	0
15.	*Distemonanthus benthamianus* Baill.	Bonsamdua (Ayan)	0.65-0.80	0	0
16.	*Entandrophragma angolense* (Welw.) C. DC (syn *E. macrophyllrum* A. Chev.)	Edinam	0.49-0.62	5	2
17.	*E. candollei* Harms	Candollei	0.65-0.72	62	1
18.	*E. cylindricum* (Sprague) Sprague	Penkwa (Sapele)	0.58-0.72	0	1
19.	*E. utile* (Dawe & Sprague) Sprague	Utile (Sipo)	0.54-0.65	0	1
20.	*Erythrophleum ivorense* A. Chev. (Syn. *E. micranthum* Harms)	Potrodom (Missanda)	0.91-1.01	0 (5 wk)	0

[a]Many of these woods possess several local names even within a single political entity. All local names listed in this table are Ghanaian [12]; names parenthesized are trade names.

[b]Most of the density data was taken from Bolza and Keating [13] and from Kribs [14] and is based on the air-dry condition of the wood.

(continued)

Table 1 — Concluded

No.	Botanical Name	Common Name[a]	Density[b] Range (g/cm^3)	Percent Termite Survival (Av)	Rating
21.	*Guarea cedrata* (A. Chev.) Pellegr. (Syn. *Trichilia cedrata* A. Chev)	Kwabohoro (Scented Guarea)	0.51-0.64	0	1
22.	*Khaya ivorensis* A. Chev.	African mahogany, (Dubini)	0.46-0.57	0	1
23.	*K. senegalensis* (Desr.) A. Juss.	Kuka	0.65-0.90	13	0
24.	*Lophira alata* Banks ex. Gaertn. f.	Kaku Azobe (Ekki)	0.89-1.12	2	0
25.	*L. lanceolata* Van Tiegh ex Keay	Sereso	0.81-0.90	0	0
26.	*Lovoa trichilioides* Harms (Syn. *L. klaineana* Pierre ex. Sprague)	Kwatannuro (Tigerwood)	0.45-0.62	0 (4 wks)	3
27.	*Mammea africana* Sabine (Syn. *Ochrocarpus africanus* Oliv.)	Bompagya	0.80	0	1
28.	*Manilkara multinervis* Dubard	Berekankum	1.09	0 (3 wk)	0
29.	*Mansonia altissima* (A. Chev.) A. Chev. (Syn. *Achantia altissima* A. Chev.)	Oprono (Mansonia)	0.58-0.72	0 (1 wk)	0
30.	*Mitragyna stipulosa* (DC.) O. Kuntze (Syn. *M. macrophylla* (Hiern))	Abura (Subaha)	0.50-0.63	0	1
31.	*Morus mesozygia* Stapf	Wonton	0.81-0.90 (4 wks)	0	0
32.	*Nauclea diderrichii* (DeWild.) Merrill (Syn. M. *sacrocephalus diderrichii* DeWild)	Kusia (Opepe)	0.65-0.90	0	0
33.	*Nesogordonia papaverifera* (A. Chev.) R. Capuron	Danta	0.73-0.80	0	1
34.	*Ongokea gore* (Hua) Pierre (Syn. *O. klaineana* Pierre)	Bodwe	0.80-1.00	19	0
35.	*Parkia bicolor* A. Chev.	Asoma	0.41-0.45	0	2
36.	*Pericopsis elata* Harms (Syn. *Afrormosia elata Harms*)	Kokrodua	0.64-0.96	0	1
37.	*Piptadeniastrum africanum* (Hook.f.) Brenan (Syn. *Piptadenia africana* Hook.f.)	Dahoma (Dahoma)	0.65-0.80	0 (1 wk)	0
38.	*Pterocarpus erinaceus* Poir ex. D.C.	African kino	0.73-0.90	4	1
39.	*Tarrietia utilis* (Sprague) Sprague	Nyankom	0.63-0.78	0	1
40.	*Terminalia ivorensis* A. Chev.	Emeri (Idigbo)	0.45-0.65	32	1
41.	*T. superba* Engl. & Diels	Ofram (Afara)	0.45-0.65	11	3
42.	*Triplochiton scleroxylon* K. Schum	Wawa (Obeche)	0.36-0.40	0	2
43.	*Pinus elliotti* Engelm. var. *elliotti*	Slash pine	0.54-0.59	91	3
44.	Sand Check			0	—

When damage was limited only to surface etching during the exposure, we suggest that death was caused either by starvation or a volatile toxic substance in the wood. Woods which were moderately or heavily damaged obviously possessed no repellent, or at best insufficient repellent, to prevent substantial feeding. Since the termites confined with *P. bicolor* and *T. scleroxylon* did not die until close to the end of the exposure period, these woods may have contained substances acting on the protozoa of the termites rather than being toxic to the termites themselves. Because the termites confined with *C. patens* and *L. trichilioides* died within 4 weeks, we suspect that a relatively slow-acting, undetectable systemic poison, ingested during feeding, was present in these woods.

Termite Survival — No Detectable Wood Damage (Group 3)

Some termites survived the 8 weeks of exposure on seven of the undamaged woods; however, survival ranged from 2% for *Lophira alata* which is considered very resistant to termite attack [13] to 52% for *Dialium aubrevillei*. Since none of these woods were detectably damaged by the insects, they must have possessed an intrinsic repellent quality. Again, one reason for the rather low termite survival on some of these woods, particularly *L. alata*, could be the presence of a toxic volatile material which emenated from the wood and saturated the exposure chamber. Possibly, a short increase in exposure time would have placed *L. alata* in Group 1.

In the case of *D. aubrevillei* starvation could be a factor since the high termite survival rate suggests that this wood was mostly repellent to the insects. The extent of termite survival on the remaining woods in this group hints that each might have contained a less potent toxic principle whose effect on most of the termites eventually reached a critical state; in the absence of such a substance a higher percentage of termites should have survived.

Termite Survival - Wood Damage (Group 4)

Coptotermes formosanus was able to survive on all of the remaining nine woods of this study; however, after the 8 weeks of exposure, survival varied from 4% to 83%, and the damage to the woods varied from light to heavy. For example, *Pterocarpus erinaceus* was only lightly damaged by *C. formosanus* during this period although only 4% of the colony survived; death was probably caused by starvation or a slow-acting toxicant. *Entandrophragma angolense* was moderately damaged by the feeding termites of which only 5% survived indicating that this wood possessed a deleterious, but not immediately effective, antitermitic component. Conversely, the 83% survival of the termites closeted with *Antrocaryon micraster* showed this wood to be about as nonresistant as the heavily damaged pine controls on which 91% of the termites survived.

Effect of Wood Density

There was a general inverse relationship between the hardness of the wood and the amount of termite damage it received. This relationship is presented in Fig. 2 which shows the air-dry density range for each of the woods (except *D. aubrevellei*) arranged according to their damage ratings. The average density for the woods comprising the set that sustained no detectable termite damage was 0.83 g/cm^3. The average density of those woods that were only lightly attacked by termites (rating — 1) was 0.67 g/cm^3, and those that were more heavily attacked (rating — 2 or 3) were also the lightest as a set, with an average density of 0.59 g/cm^3. These density results contrast to those of an earlier field study [6] that showed that after 158 months' exposure of 112 tropical woods in the Panamanian forest, about one-quarter of those woods

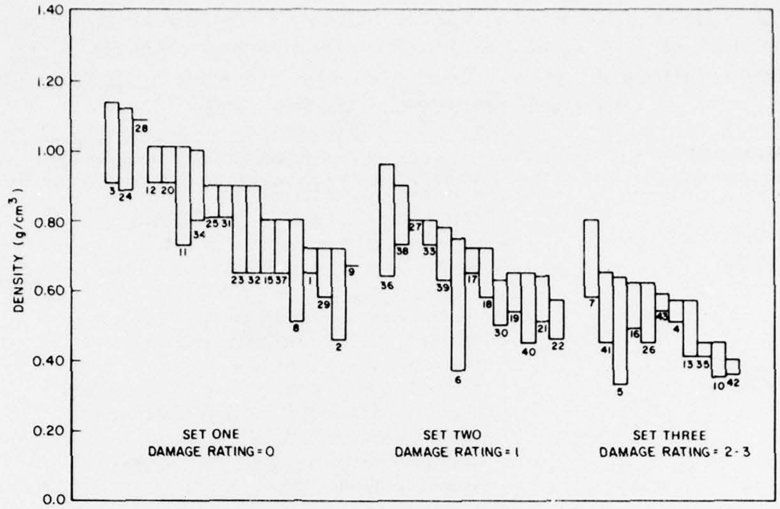

Fig. 2 — Termite damage as a function of wood density by rating sets. Each bar represents the density range reported for that wood; a line represents a single value. Refer to Table 1 for wood identifications.

heavily damaged by termites had an air-dry density of at least 0.9 g/cm^3 and about one-third of those woods undamaged or lightly damaged by termites had an air-dry density of 0.7 g/cm^3 or less. Thus, for these woods, density did not contribute to their resistance, or lack of it.

Comparative Exposure Data

Many of these 42 woods have been evaluated elsewhere for natural termite resistance, and some of these results are compared with those of the present study in Tables 2, 3, and 4. In several instances other species of the same genera are included for comparison, particularly when specific data from other sources were not uncovered. For reader interest marine borer data are also included when available. Although often not specified, it is presumed that the literature information refers to heartwood since sapwood is generally nonresistant to biodegradation. In Tables 2 and 3 the woods have been grouped according to a common resistance rating of 0 and 1, respectively; woods with resistance ratings of 2 or 3 have been combined in Table 4. Unfortunately, some of the literature ratings are contradictory, and often the termite species is not given. However, a good correlation is evident between the results from this work and the published data for all woods listed in Tables 2 and 4. The correlation between the exposure results for those woods lightly damaged by *C. formosanus* (Table 3) and the published data is not as good. The published information generally indicates that these woods were more susceptible to termite damage than the results of the present study indicate.

One of the major causes for contradictory exposure data for a particular wood is the vigor and variation of the termite species to which the wood has been exposed; data from laboratory exposures [15] show a significant difference in the aggressiveness of different termite species and in the feeding pressure they can impose. Variations in experimental conditions can also influence the results. Another contributing factor relates to the original position of the wood specimen in the bole. As previously stated, it is generally the heartwood of a tree that possesses natural resistance to biodegradation, and frequently resistance of the wood decreases

Table 2 — None of the listed woods were detectably damaged by *Coptotermes formosanus.* Data from other sources which substantiate or conflict with the observed resistance of these woods are presented. For reader interest marine borer data are included when available.

Botanical Name	Published Termite Resistance Data
Afzelia bella	*A. bella* is reported resistant to termites and teredoes [13], although it is the experience of one of us (F.F.K.A.) that this wood is readily attacked by teredos. *A. quanzensis* is reported resistant to termites [25], and *A. africana* is reported specifically resistant to *Reticulitermes lucifugus* [26].
Albizia ferruginea	*A. ferruginea* is reputedly resistant to termites in Nigeria [19,27,28]; moderately resistant elsewhere [11]. *A. coriaria* was free of termite attack after 66 months' exposure in Ghana [29].
Anogeissus leiocarpus	*A. leiocarpus* is reported resistant to termites [12,13]. A related species, *A. latifolia,* is reported moderately resistant to *Microcerotermes beesoni* [30].
Chlorophora excelsa	*C. excelsa* is reported practically immune to termite damage [11] and resistant to marine organisms [13] although variously resistant to terrestrial woodborers. The wood is very resistant (repellent) to *Cryptotermes brevis* [31] and is moderately damaged by *Pseudacanthotermes militaris* in Ghana [32]. Chlorophorin, an antitermitic extractive in the wood, is effective against *R. lucifugus* [33]. *C. tinctoria* of Panama sustained only a trace of damage after 158 months in the Panamanian forest [6]. *C. regia* is resistant to *R. lucifugus* [26]; 20% of the specimens failed after 66 months' exposure in Ghana [29].
Chrysophyllum pruniforme	No information was uncovered for this species; however, *C. cainito* of Panama was heavily damaged by termites after 90 months in the Panamanian forest [6].
Combretodendron macrocarpum	*C. macrocarpum* is reported resistant to termites in Nigeria and to other insects [12,19,27].
Coula edulis	*C. edulis* is reported immune to termite attack [12] and only moderately attacked by marine borers [13].
Distemonanthus benthamianus	*D. benthamianus* is reported termiteproof [12], or moderately resistant to *C. brevis* [31] and *R. lucifugus* [26]. Its resistance to marine borers varies with silica content of the wood [13].
Erythrophleum ivorense	*E. ivorense* is reported resistant to termites and teredos [12,19] and very durable in ground contact [13]; *E. africanum* is reported termiteproof [34], *E. guineense* is resistant and repellent to *R. lucifugus,* [35], and E. *laboucherii,* an Australian wood, is reported resistant and repellent to termites [36].

(continued)

Table 2 — Concluded

Botanical Name	Published Termite Resistance Data
Khaya senegalensis	*K. senegalensis* is reported particularly resistant to termites [12,13,27]; *K. anthotheca* was almost completely destroyed after 18 months' exposure in Uganda [29].
Lophira alata	*L. alata* is reported impervious to insects [12], resistant, but not immune, to termites [19,27], and also resistant to marine borers [20]. Specifically, *L. alata* is resistant to attack by *R. lucifugus* [26].
Lophira lanceolata	*L. lanceolata* is reported resistant to termites and moderately resistant to marine borers [13].
Manilkara multinervis	*M. multinervis* is considered resistant to termites [12], and two related species, *M. bidentata* and *M. huberi*, are moderately resistant and very resistant (repellent), respectively, to *C. brevis* [31]. *M. bidentata* and *M. chicle* of Panama were lightly damaged by termites after 158 months' exposure in the Panamanian forest [6].
Mansonia altissima	*M. altissima* is reputedly resistant to termites [12,24] but less so to other insects [37]; it is classified as resistant to *R. lucifugus* [26], to *P. militaris* in Ghana [32], and fairly resistant to termites in Nigeria [27].
Morus mesozygia	*M. mesozygia* is reported to be liable to termite and marine borer attack [13]; *M. alba* resisted attack by the termites *Anacanthotermes ochraceus*, *Psammotermes fuscofemorales*, and *P. assurensis* for 6 months [38], and *M. ruba* is very susceptible to attack by *C. brevis* [31].
Nauclea diderrichii	*N. diderrichii* is classified as resistant to termites and also marine borers [12,13]; specifically, it is reported resistant to *R. lucifugus* [26].
Ongokea gore	*O. gore* is reported as rarely attacked by termites or marine borers [13].
Piptadeniastrum africanum	Contradictory information exists regarding the termite resistance of *P. africanum*. It is classified as resistant in Nigerian tests and nonresistant in tests conducted in South Africa [12], where it was unable to resist termite attack for more than three years [24,27]; Ugandan tests produced a 70% failure of panels in 4 years [29]. The wood is classified as resistant to *R. lucifugus* [26].

Table 3 — All the listed woods were lightly damaged (rating — 1) by *Coptotermes formosanus.* Data from other sources which substantiate or conflict with the observed resistance of these woods are presented. For reader interest marine borer data are included when available.

Botanical Name	Published Termite Resistance Data
Cedrela mexicana	*C. mexicana* is reported very termite resistant in Guyana and in the West Indies [27], but a related species, *C. fissilis*, is very susceptible to attack by *Cryptotermes brevis* [31]. *C. mexicana* was only lightly damaged by termites after 90 months' exposure in the Panamanian forest [6].
Entandrophragma candollei	*E. candollei* is reported to have negligible resistance to *Pseudacanthotermes militaris* in Ghana [32] and to be moderately resistant to termites and liable to marine borer attack [13].
E. cylindricum	*E. cylindricum* is reported nonresistant to termites [12,13] and marine borers [13] and is damaged by other insects. It is also reported as being moderately resistant to termites in Nigeria [27] and Uganda [29] and moderately resistant to *P. militaris* in Ghana [32].
E. utile	The heartwood of *E. utile* is reported as moderately resistant to termites and as not resistant to termites [12,13,19], specifically *P. militaris* in Ghana [32], and moderately resistant to marine borers [13].
Guarea cedrata	*G. cedrata* is reported moderately resistant to termites [12,13,20], and as having fairly high resistance to *P. militaris* in Ghana [32]. Two other species, *G. longipetiola* and *G. guara*, were lightly damaged by termites after 90 and 158 months' exposure, respectively, in the Panamanian forest [6].

(continued)

Table 3 — Concluded

Botanical Name	Published Termite Resistance Data
Mammea africana	*M. africana* is reported as moderately susceptible to termites but resistant to attack by marine borers of the genus Xylophaga [13]. Specifically, it is not resistant to *C. brevis* [31].
Mitragyna stipulosa	*M. stipulosa* is reported as susceptible to attack by termites and other insects [19,24]. *M. parvifolia* is reported very susceptible to attack by the drywood termite *Neotermes bosei* [39].
Nesogordonia papaverifera	*N. papaverifera* is reported resistant to termites and other insects [12,27] but susceptible to marine borers [13].
Pericopsis elata	*P. elata* is considered very durable [12] with fairly high resistance to *P. militaris* [32]; it has better than average resistance to insect attack [37] and resistance to teredos [14,28].
Pterocarpus erinaceus	*P. erinaceus* is reported as moderately to very resistant to termites [13]; a related species, *P. angolensis*, is classified as resistant to termites in South Africa, Tanzania, and Northern Rhodesia [27]. Other species, *P. dalbergioides* [27] and *P. indicus* [36], are also reported to be resistant.
Tarrieta utilis	*T. utilis* is moderately resistant to termites and to other insects [12,24,37] and specifically resistant to *Reticulitermes lucifugus* [26].
Terminalia ivorensis	*T. ivorensis* is classed as susceptible to termite attack [12,24] and as having fairly high resistance to *P. militaris* in Ghana [32]. Specifically, it is classified as fairly susceptible to attack by *C. brevis* [31]. Three other species, *T. amazonia*, *T. myriocarpa*, and *T. catappa*, were only lightly damaged by termites after 30 months' exposure in the Panamanian forest [6].

Table 4 — All the listed woods were moderately (rating — 2) or heavily (rating — 3) damaged by *Coptotermes formosanus.* Data from other sources which substantiate or conflict with the observed resistance of these woods are presented. For reader interest marine borer data are included when available.

Botanical Name	Published Termite Resistance Data
Canarium schweinfurthii (3)[a]	*C. schweinfurthii* is classified as nonresistant to termites and other insects [12,19,27], although the resin is used in insecticide powders.
Celtis mildraedii (2)	*C. mildbraedii* is reported nonresistant to termites [12,13,17].
Cleistopholis patens (2)	*C. patens* is reported liable to marine borer attack [13]; reports of termite resistance are variable [11].
Daniellia ogea (3)	*D. ogea* is considered not durable [37]. It is reported as not resistant to termites [19] and is attacked by marine borers [13]. A related species, *D. oliveri*, is also susceptible to termite attack [29].
Entandrophragma angolense (2)	*E. angolense* is reported as moderately resistant to termites in Nigeria [19,27] and in Uganda [29], negligibly resistant to *Pseudacanthotermes militaris* in Ghana [32], and susceptible to attack by boring insects [20] and marine borers [13].
Lovoa trichilioides (3)	Although *L. trichilioides* is generally considered susceptible to attack by wood-boring organisms [12,20], it is regarded as moderately resistant to termites in Nigeria [19] and to marine borers [13]. It is reported by one of us (F.F.K.A.) as being riddled by teredos in 5 months in Ghanaian tests.
Parkia bicolor (2)	*P. bicolor* is prone to attack by termites and other insects, and by marine borers [13].
Terminalia superba (3)	*T. superba* is classified as not resistant to termites [12,13,19,27], specifically *Reticulitermes lucifugus* [26]; it is not resistant to marine borers [13]. (Compare with *T. ivorensis*, Table 3).
Triplochiton scleroxylon (2)	*T. scleroxylon* is reported susceptible to attack by termites and other insects [12,13,24], specifically by *R. lucifugus* [26] and by *P. militaris* in Ghana [32].

[a] The parenthized number is the damage rating.

radially toward the pith and with elevation above the ground. Intraspecific variations in natural resistance can also occur as a function of the geographic location of a tree, and the exposure method can also exert an influence; for example, variation in wood specimen length or size may exert a significant influence on the total amount of wood eaten [16]. Many, or all, of these factors may have contributed to the observed resistance of the woods in this study and to the resistance data reported by others.

WOODS OF SPECIAL INTEREST

Many of the woods examined in this study possess other outstanding qualities in addition to their resistance to termites. Some are noted for their resistance to fungal infection and to marine boring organisms; they also exhibit physical characteristics that make them desirable for use in certain types of manufacturing or construction. Five of these woods have been selected for special mention because of their commercial value.

Chlorophora excelsa, or Odum (Iroko)

Iroko ranges across equatorial Africa from the Ivory Coast to Tanzania and southward into Mozambique; it is a very large forest tree often attaining a height of 49 m (160 ft) and a diameter of 3 m (10 ft). Iroko is a strong, moderately hard and heavy wood with the density given as 0.65 to 0.76 g/cm^3 based on an oven-dry weight and volume [17]. In addition to its termite resistance, it is also resistant to attack by marine boring organisms and is considered to be very resistant to decay; an extractive, chlorophorin, which has antifungal worth, has been isolated from this wood [18]. Although iroko works well, tools used in cutting and dressing the wood become dulled because of the presence of calcium carbonate deposits. Iroko is used for heavy construction, the manufacture of furniture and cabinets, in millwork, and for paneling, flooring, and railroad ties. Iroko is very resistant to preservative treatment [19].

Lophira alata, or Kaku (Ekki)

Ekki ranges across equatorial Africa from Sierra Leone to Gabon and the Congo [12]; it is a very large forest tree, often attaining a height of 49 to 55 m (160 to 180 ft) and a bole diameter of 2 m (6 ft). Ekki is a very heavy, hard wood rated as one of the most durable on the west coast of Africa [18]. The density is given as 0.80 to 1.02 g/cm^3 based on its oven-dry weight and air-dry volume [20]. In addition to its termite resistance, ekki is also resistant to attack by other insects and by marine boring organisms [19,21]; it is also considered highly resistant to decay [19]. Ekki is difficult to season, to saw, and to machine and is usually used in heavy construction for such applications as piling, bridges, and wharves [19]. It is also used for heavy flooring and railroad ties. It is very resistant to treatment with preservatives.

Nauclea diderrichii, or Kusia (Opepe)

Opepe ranges across equatorial Africa from Sierra Leone to Uganda and produces a moderately heavy wood (d = 0.65 to 0.90 g/cm^3). Opepe is a moderately large and slim tree, reaching a height of 37 m (120 feet) and a diameter of about 1 meter (3 ft). Besides being resistant to termites, it is also resistant to attack by marine boring organisms and to fungal infection [12]. Because of its strength and durability, it is suitable for heavy-duty construction such as marine piling, bridges, wharves, planking, and railroad ties. Opepe works and finishes moderately well [12] and thus can be used for interior finishing, cabinet work, and turnery. The wood contains an alkaloid reputedly is a cumulative cardiac poison and has caused death among handlers [22].

Erythrophyleum ivorense, or Potrodon (Missanda)

Missanda ranges along the coast of the Gulf of Guinea from Sierra Leone to Gabon and produces a very heavy, durable wood which is rather difficult to work. Although not particularly abundant throughout its range, its durability warrants inclusion here [12]. The air-dry density is given as 0.91 to 1.01 g/cm^3) [13]. The red-brown wood is used primarily for light construction and carpentry, and in heavy construction for such applications as harbor installations and piling because of its marine borer resistance [19]. It is also used for railroad ties and in bridges.

Mansonia altissima, or Oprono (Mansonia)

Mansonia has a restricted range through tropical Africa, extending from the Ivory Coast to Nigeria. Mansonia is a moderately tall forest tree attaining a height of 30 to 37 m (100 to 120 ft) and a diameter of about 0.6 m (2 ft). The wood is moderately hard and heavy with an air-dry density of 0.58 to 0.72 g/cm^3 [13]. Besides being termite resistant, mansonia is also resistant to decay, and the sawdust is irritating to the mucous membranes of some individuals [23,24]. The irritant may be the wood constituent responsible for the complete mortality within 1 week of the captive *C. formosanus* colony in this study. The wood seasons easily, works well with machine and hand tools, and finishes well. Mansonia has many applicatons in carpentry, as interior paneling, and in the manufacture of furniture and musical instruments.

SUMMARY

The natural resistance of 42 tropical African woods to damage by *Coptotermes formosanus* in a laboratory force-feeding situation was determined. Most of the woods were not detectably damaged, or only superficially damaged, during the 8 weeks of exposure to this voraceous Asian termite. Complete mortality of the small groups of termites that were confined with 18 of these woods was recorded by the end of the exposure period.

The termites that were confined with eight others of these woods succumbed well before the end of the exposure, the survival time varying from 1 to 5 weeks. Termites in exposure chambers containing *Mansonia altissima* or *Piptadeniastrum africanum* were all dead within a week with no detectable damage to the wood; those exposed to *Albizia ferruginea, Manilkara multinervis, Morus mesozygia*, and *Erythrophleum ivorense* were all dead within 2, 3, 4, and 5 weeks, respectively, also with no detectable wood damage. Active feeding by *C. formosanus* occurred on the two remaining woods. The termites moderately damaged *Cleistopholis patens* during the 4 weeks they were able to survive confined with this wood; *Lovoa trichilioides* was heavily damaged by termites in the 4 weeks before mortality occurred.

There was an inverse relationship between the wood density and attack by *C. formosanus*, with the lighter, softer woods being more severely damaged than the heavier, harder woods. Some of the woods in this study have been evaluated elsewhere for natural termite resistance. Correlation between previously published results and those reported here is good for those woods that were not detectably damaged or were moderately to heavily damaged by *C. formosanus*; correlation with previously published data was not as good for those woods of this study which were lightly damaged, with the prior data indicating a greater susceptibility to termite attack than that observed in this study.

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Appendix

COMMON AND BOTANICAL NAMES OF THE WOODS

Abura, *Mitragyna stipulosa*
Achantia altissima = *Mansonia altissima*
Afara, *Terminalia ivorensis*
African kino, *Pterocarpus erinaceus*
African mahogany, *Khaya ivorensis*
Afrormosia elata = *Pericopsis elata*
Afzelia bella, Papao
Albizia ferruginea, Awiemfo-samina, Albizzia
Albizzia, *Albizia ferruginea*
Anogeissus leiocarpus, Kane
Antrocaryon micraster, Aprokuma
Aprokuma, *Antrocaryon micraster*
Asoma, *Parkia bicolor*
Awiemfo-samina, *Albizia ferruginea*
Ayan, *Distemonanthus benthamianus*
Azobe, *Lophira alata*
Bediwonua, *Canarium schweinfurthii*
Berekankum, *Manilkara multinervis*
Bodwe, *Coula edulis*, *Ongokea gore*
Bompagya, *Mammea africana*
Bonsamdua, *Distemonanthus benthamianus*
Canarium schweinfurthii, Bediwonua
Candollei, *Entandrophragma candollei*
Cedrela mexicana, West India cedar
C. odorata = *C. mexicana*
Celtis mildbraedii, Esa
C. soyanxii = *C. mildbraedii*
Chlorophora excelsa, Odum, Iroko
Chrysophyllum pruniforme, Duatadwe
Cleistopholis patens, Ngo Ne Nkyene
Combretodendron africanum, = *C. macrocarpum*
C. macrocarpum, Essia
Coula edulis, Bodwe
Dahoma, *Piptadeniastrum africanum*
Daniellia ogea, Hyedua, Ogea
D. similis = *D. ogea*
Danta, *Nesogordonia papaverifera*
Dialium aubrevillei, Dua-bankye
Distemonanthus benthamianus, Ayan, Bonsamdua
Dua-bankye, *Dialium aubrevillei*
Duatadwe, *Chrysophyllum pruniforme*
Dubini, *Khaya ivorensis*
Edinam, *Entandrophragma angolense*
Ekki, *Lophira alata*
Emeri, *Terminalia ivorensis*
Entandrophragma angolense, Edinam
E. candollei, Candollei
E. cylindricum, Penkwa, Sapele
E. macrophylla = *E. angolense*
E. utile, Utile, Sipo
Erythrophleum ivorense, Potrodon, Missandra
E. micranthum - *E. ivorense*
Esa, *Celtis mildbraedii*
Essia, *Combretodendron macrocarpum*
Guarea cedrata, Kwabohoro
Hyedua, *Daniellia ogea*
Idigbo, *Terminalia ivorensis*
Iroko, *Chlorophora excelsa*
Kaku, *Lophira alata*
Kane, *Anogeissus leiocarpus*
Khaya ivorensis, African mahogany, Dubini
K. senegalensis, Kuka
Kokrodua, *Pericopsis elata*
Kuka, *Khaya senegalensis*
Kusia, *Nauclea diderrichii*
Kwabohoro, *Guarea cedrata*
Kwatannuro, *Lovoa trichilioides*
Lophira alata, Ekki, Kaku
L. lanceolata, Sereso
Lovoa klaineana = *L. trichilioides*
L. trichilioides, Kwatannuro, Tigerwood
Mammea africana, Bompagya
Manilkara multinervis, Berekankum
Mansonia, *Mansonia altissima*
Mansonia altissima, Oprono, Mansonia
Missanda, *Erythrophleum ivorense*
Mitragyna macrophylla = M. *stipulosa*
M. stipulosa, Abura
Morus mesozygia, Wonton
Nauclea diderrichii, Opepe, Kusia

Nesogordonia papaverifera, Danta
Ngo Ne Nkyene, *Cleistopholis patens*
Nyankom, *Tarrietia utilis*
Obeche, *Triplochiton scleroxylon*
Ochrocarpus africanus = *Mammea africana*
Odum, *Chlorophora excelsa*
Ofram, *Terminalia superba*
Ogea, *Daniellia ogea*
Ongokea gore, Bodwe
O. klaineana = *O. gore*
Opepe, *Nauclea diderrichii*
Oprono, *Mansonia altissima*
Papao, *Afzelia bella*
Parkia bicolor, Asoma
Penkwa, *Entandrophragma cylindricum*
Pericopsis elata, Kokrodua
Piptadenia africana = *Piptadeniastrum africanum*
Piptadeniastrum africanum, Dahoma
Potrodom, *Erythrophleum ivorense*
Pterocarpus erinaceus, African kino
Sapele, *Entandrophragma cylindricum*
Sarcocephalus diderrichii = *Nauclea diderrichii*
Scented guarea, *Guarea cedrata*
Sereso, *Lophira lanceolata*
Sipo, *Entandrophragma utile*
Tarrietia utilis, Nyankom
Terminalia ivorensis, Idigbo, Emeri
T. superba, Afara, Ofram
Tigerwood, *Lovoa trichilioides*
Trichilia cedrata = *Guarea cedrata*
Triplochiton scleroxylon Obeche, Wawa
Utile, *Entandrophragma utile*
Wawa, *Triplochiton scleroxylon*
West Indian cedar, *Cedrela mexicana*
Wonton, *Morus mesozygia*